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(54) HEART-FREQUENCY METER

(71) We, SIEMENS AKTIENGESELLSCHAFT, a German company of Berlin and Munich, Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a heart-frequency meter, for example a heart-frequency meter with which the foetal heart frequency may be determined.

A heart-frequency meter may be constructed which operates in accordance with the ultrasonic Doppler principle, such a meter comprising a transmitter for applying an ultrasonic signal to a heart, a receiver for picking up from the heart a reflection of that signal which is modulated with Doppler signals as a result of heart pulsation, and a Doppler discriminator for providing the Doppler signals. With such a meter, the requirement exists to derive one single defined voltage pulse per heart-beat period from the Doppler signals, which tend to be very complex and subject to considerable fluctuations in amplitude and frequency composition, more especially during continuous monitoring of the heart. A digital-analogue converter or other means can then be employed to provide a unidirectional voltage which is proportional to the pulse repetition rate of the pulse train constituted by the successive voltage pulses produced. This unidirectional voltage is then a direct measure of heart frequency.

According to the present invention, there is provided a heart-frequency meter, comprising a transmitter for applying an ultrasonic signal to a heart, a reciver for picking up from the heart a reflection of that signal which is modulated with Doppler signals as a result of heart pulsation, selective frequency filter means arranged to supply to demodulator means of the meter substantially only those components of the modulated signal that are associated with a predetermined one of the two types of heart pulsation movement which respectively comprises movement towards and movement away from the transmitter, and analyzing circuitry for deriving from Doppler signals supplied thereto by the demodulator means a pulse train whose pulse repetition rate is a measure of heart frequency.

The selective frequency filter means of a meter embodying the invention will generally comprise a single selective frequency filter tuned to frequencies in the modulated signal which are characteristic of the predetermined one of the two types of heart pulsation movement mentioned. Such a selective frequency filter may for example comprise a quartz filter.

The transmitter of a meter embodying the invention may be adapted to provide the ultrasonic signal at a transmission frequency of substantially 1.5 MHz, in which case the selective frequency filter means of the meter preferably comprises a selective frequency filter having a resonance frequency which differs from the transmission frequency by substantially 200 Hz. Preferably, too, the edge steepness of any such selective frequency filter should be such that frequency components of the modulated signal that deviate from the resonance frequency of the selective frequency filter by 200 Hz are damped by substantially 20 dB or so.

Choice of a transmitter with a transmission frequency of about 1.5 MHz and of a selective frequency filter with a resonance frequency differing from the transmission frequency by about 200 Hz permits an optimum selection to be achieved with the selective frequency filter if, as mentioned above, the frequency filter has an edge steepness causing frequency components of the modulated signal that deviate from the resonance frequency by about 200 Hz to be damped by about 30 dB. Where the measurement of foetal heart frequency is concerned, the resonance frequency of the selective frequency filter is preferably about 200 Hz lower than the transmission frequency. Practice has shown that if the resonance fre-

quency is thus chosen, disturbing influences emanating from the mother's heart pulsations may be prevented in an optimum manner.

The analyzing circuitry of a heart-frequency meter embodying the invention may comprise first suppressor means for suppressing from the Doppler signals supplied by the demodulator means components of frequency higher than a predetermined maximum frequency that Doppler components arising from movement of the cardiac wall would be expected to have, additional demodulator means for effecting amplitude demodulation of the output from the first suppressor means, second suppressor means for suppressing components of the output from the additional demodulator means that are of frequency higher than the maximum frequency the heart would be expected to have, differentiator means for differentiating the output from the second suppressor means, and pulse generator means for emitting a pulse each time the output from the differentiator means exceeds a predetermined value, thereby to form the above-mentioned pulse train which is a measure of heart frequency.

For suppression from the Doppler signals supplied by the first-mentioned demodulator means of components of frequency higher than a predetermined maximum frequency that Doppler components arising from movement of the cardiac wall would be expected to have, the first suppressor means preferably comprise a low-pass filter having a cut-off frequency of substantially 200 Hz or so and an edge steepness of substantially 40 dB/octave or so. The additional demodulator means may comprise rectifier means for rectifying the output from the first suppressor means, and integrator means for integrating the output from the rectifier means. The employment of suitable integrator means, which may be constructed at relatively low cost, makes it possible to suppress brief disturbing pulses automatically.

To effect frequency limitation of the output from the additional demodulator means, the second suppressor means of a heart-frequency meter embodying the invention preferably comprise a low-pass filter having a cut-off frequency substantially equal to the maximum frequency the heart would be expected to have, for example an active Butterworth low-pass filter having an edge steepness of substantially 35 dB/octave or so. In the case of foetal heart measurement, the second suppressor means preferably comprise a low-pass filter having a cut-off frequency of substantially 3 Hz or so.

The differentiator means of a heart-frequency meter embodying the invention may comprise a plurality of differentiating devices connected in series with one another, there preferably being two such devices with a low-pass filter connected between them that has a cut-off frequency substantially equal to the maximum frequency the heart would be expected to have, for example a Butterworth low-pass filter having an edge steepness of substantially 20 dB/octave or so. Where foetal heart measurement is concerned, the cut-off frequency of any such filter should be substantially 3 Hz or so.

The pulse generator means of a heart-frequency meter embodying the invention may comprise amplifier means adapted to be fully driven by the output of the differentiator means, a Schmitt trigger connected to receive the output of the amplifier means, and a monostable trigger device connected to receive the output of the Schmitt trigger, the monostable trigger device being adapted to supply the required pulse train as a succession of like pulses of constant pulse duration. Preferably, this pulse duration is substantially 225 milliseconds or so.

The pulse train supplied by a heart-frequency meter embodying the invention as a measure of heart frequency preferably takes the form of a train of voltage pulses.

The suppression of those components of the modulated signal that are associated with one of the two types of heart pulsation movement, this suppression being effected in the selective frequency filter means of a heart-frequency meter embodying the invention, gives simplified Doppler signals which facilitate the production of the desired pulse train. By limiting the Doppler frequency spectrum to frequencies which are lower than or equal to the maximum frequency to be expected of the components arising from the movement of the cardiac wall, there are suppressed more particularly those Doppler components of higher frequency that are associated with the cardiac valves and can cause double counting because they appear with time displacement in relation to the cardiac wall reflection. Owing to the subsequent amplitude demodulation and the corresponding frequency-clipping of the demodulation signal, a generally sinusoidal oscillation having the frequency of the heartbeat is obtained. However, by reason of changes in the position of the heart (which are caused above all by movements of the child in the measurement of the foetal heart frequency) and body movements, there are often superimposed upon this oscillation low-frequency disturbing oscillations which are sometimes even within the heart frequency range. The level of the points of reversal of the sinusoidal oscillation in relation to the zero line is thereby subjected to considerable fluctuations. Moreover, the amplitude of the sinusoidal oscillation may vary within wide limits. By differentiation of the frequency-limited demodulation signal, these

fluctuations are substantially balanced out, because exact passages through zero are created from the greatly varying points of reversal and differing amplitudes are converted into differing steepnesses of the passages, through zero. By subsequent pulse conversion of this sinusoidal oscillation, the desired train of pulses (for example, voltage pulses) may be obtained in step with the actual heart frequency.

For a better understanding of the invention, and to show how it can be carried into effect, reference will now be made, by way of example, to the accompanying diagrammatic drawing, which is a schematic block circuit diagram of a heart-frequency meter embodying the invention.

The illustrated heat-frequency meter comprises an ultrasonic transmitter 1 for applying an ultrasonic signal to a heart whose frequency is to be monitored, and a co-operating receiver 2 (comprising a piezo-electric crystal) for picking up from the heart a reflection of the ultrasonic transmission signal which is modulated with Doppler signals as a result of heart pulsation. The heart towards which ultrasonic energy emitted by the transmitter 1 is directed may for example be the heart of a foetus. The transmitter is fed by a high-frequency generator 3 (a quartz stabilized oscillator) tuned to have a frequency f_o of 1.5002 MHz. The modulated signal picked up from the heart by the receiver 2 is applied, after amplification in a high-frequency amplifier 4, to selective frequency filter means in the form of a quartz filter 5 with a resonance frequency f_r of 1.5 MHz and an edge steepness chosen such that frequency components differing from the resonance frequency by 200 Hz are damped by about 20 dB. The output of the quartz filter 5 is connected via a high-frequency amplifier 6 to a Doppler discriminator 7 corresponding to the "demodulator means" mentioned hereinbefore.

Because of the action of the quartz filter 5, the Doppler discriminator 7 is supplied substantially only with those components of the above-mentioned modulated signal that are associated with heart pulsation movement away from the ultrasonic transmitter 1 (and the receiver 2). From those components of the modulated signal reaching the Doppler discriminator 7, the discriminator provides an output comprising the corresponding Doppler signals. This output is applied, on the one hand, through a first low-frequency amplifier 8 to a volume amplifier 9 for producing a Doppler noise, and, on the other hand, through a second low-frequency amplifier 10 having an automatic amplitude-equalizing device 11 to a 200-Mz low-pass filter 12 having an edge steepness of 40 dB/octave. The low-pass filter 12 limits the Doppler frequency spectrum 13 of the output from the amplifier 10 to frequencies which are lower than or equal to the highest frequency to be expected of the Doppler components (200 Hz) from the movement of the cardiac wall, that is to say components of higher frequency emanating from the movement of the cardiac valves are suppressed. The thus frequency-clipped output of the filter 12 is indicated by the reference numeral 14.

The output 14 is applied through a rectifier 15 (diode) to an integrator 16 for effecting amplitude demodulation. The integrator 16 provides an envelope 17 for the output 14. Pulses of brief duration which might cause disturbances are automatically suppressed by the integrator 16.

The output of the integrator 16 is applied to an active low-pass filter 18 having a cut-off frequency of 3 Hz. This filter is constructed as a Butterworth low-pass filter and has an edge steepness of 35 dB/octave. The filter 18 provides a voltage output 19 of generally sinusoidal form having the frequency of the heart being monitored.

The output 19 is differentiated in a first differentiating device 20 so as to eliminate the influence of any superimposed relatively low-frequency disturbing voltages due, for example, to changes in position of the heart and/or body movements. The differentiation causes high points of reversal at different levels in relation to the zero line to be converted into accurate passages through zero and amplitudes of different height to be converted into different steepnesses of the passages through zero. The differentiated output 31 provided by the differentiating device 20 is applied, after amplification in an amplifier 22, to a second 3-Hz low-pass filter 23 (preferably a Butterworth filter having an edge steepness of 20 dB/octave) for further frequency limitation. After further differentiation in a second differentiating device 24 to effect further improvement in amplitude equalization, the differentiated signal 25 is applied to an amplifier 26 which is connected to apply its output to a Schmitt trigger 27 which, in turn, applies its output to a monostable trigger device 28.

The amplifier 26 is so designed that it is fully driven by the differentiated signal 25. The resultant square-wave output of the amplifier is given steeper edges by the Schmitt trigger 27. By means of their positive-going edges, the pulses in the output from the Schmitt trigger 27 trigger the monostable trigger device 28 to emit respective standardised pulses 29 having a duration of 225 milliseconds and an amplitude of 6 volts. The standardised pulses 29 thus generated are converted by a digital-analogue converter 30 into a frequency-proportional

unidirectional voltage, which is a direct measure of the heart frequency.

A recorder 31 connected to receive the output from the converter 30 serves for the continuous recording of the heart frequency, while an indicating instrument 32 also connected to receive the output of the converter 30 serves to indicate the momentary heart frequency.

WHAT WE CLAIM IS:—

1. A heart-frequency meter, comprising a transmitter for applying an ultrasonic signal to a heart, a receiver for picking up from the heart a reflection of that signal which is modulated with Doppler signals as a result of heart pulsation, selective frequency filter means arranged to supply to demodulator means of the meter substantially only those components of the received modulated signal that are associated with a predetermined one of the two types of heart pulsation movement which respectively comprise movement towards and movement away from the transmitter, and analyzing circuitry for deriving from Doppler signals supplied thereto by the demodulator means a pulse train whose pulse repetition rate is a measure of heart frequency.

2. A meter as claimed in claim 1, wherein the selective frequency filter means comprises a quartz filter.

3. A meter as claimed in claim 1 or 2, wherein the transmitter is adapted to provide the said ultrasonic signal at a transmission frequency of substantially 1.5 MHz and the selective frequency filter has a resonance frequency which differs from the said transmission frequency by substantially 200 Hz.

4. A meter as claimed in claim 3, wherein the edge steepness of the selective frequency filter means is such that frequency components of the said modulated signal that deviate from the said resonance frequency by 200 Hz are damped by substantially 20 dB.

5. A meter as claimed in claim 3 or 4, wherein the said resonance frequency is substantially 200 Hz lower than the said transmission frequency.

6. A meter as claimed in any preceding claim, wherein the said analyzing circuitry comprises first suppressor means for suppressing from the Doppler signals supplied by the said demodulator means components of frequency higher that a predetermined maximum frequency that Doppler components arising from the movement of the cardiac wall would be expected to have, additional demodulator means for effecting amplitude demodulation of the output from the first suppressor means, second suppressing components of the output from the said additional demodulator means that are of frequency higher than the maximum frequency the heart would be expected to have, differentiator means for differentiating the output from the second suppressor means, and pulse generator means for emitting a pulse each time the output from the differentiator means exceeds a predetermined value, thereby to form the said pulse train.

7. A meter as claimed in claim 6, wherein the said first suppressor means comprise a low-pass filter having a cut-off frequency of substantially 200 Hz and an edge steepness of substantially 40 dB/octave.

8. A meter as claimed in claim 6 or 7, wherein the said additional demodulator means comprise rectifier means, for rectifying the output from the said first suppressor means, and integrator means for integrating the output from the rectifier means.

9. A meter as claimed in claim 6, 7 or 8, wherein the said second suppressor means comprise a low-pass filter having a cut-off frequency substantially equal to the maximum frequency the heart would be expected to have.

10. A meter as claimed in claim 9, wherein the said second suppressor means comprise an active Butterworth low-pass filter having an edge steepness of substantially 35 dB/octave.

11. A meter as claimed in claim 9 or 10, wherein the said second suppressor means comprise a low-pass filter having a cut-off frequency of substantially 3 Hz.

12. A meter as claimed in any one of claims 6 to 11, wherein the differentiator means comprise a plurality of differentiating devices connected in series with one another.

13. A meter as claimed in claim 12, wherein the said differentiating devices are two in number.

14. A meter as claimed in claim 13, including a low-pass filter connected between the said differentiating devices, which filter has a cut-off frequency substantially equal to the maximum frequency the heart would be expected to have.

15. A meter as claimed in claim 14, wherein the low-pass filter connected between the said differentiating devices comprises a Butterworth low-pass filter having an edge steepness of substantially 20 dB/octave.

16. A meter as claimed in claim 14 or 15, wherein the low-pass filter connected between the said differentiating devices has a cut-off frequency of substantially 3 Hz.

17. A meter as claimed in any one of claims 6 to 16, wherein the said pulse generator means comprise amplifier means adapted to be fully driven by the output of the said differentiator means, a Schmitt trigger connected to receive the output of the amplifier means, and a monostable trigger device connected to receive the output of

the Schmitt trigger, the monostable trigger device being adapted to supply the said pulse train as a succession of like pulses of constant pulse duration.

18. A meter as claimed in claim 17, wherein the pulse duration of the pulses of the said pulse train is substantially 225 milliseconds.

19. A meter as claimed in any preceding claim, wherein the pulse train comprises a succession of voltage pulses.

20. A heart-frequency meter, substantially as hereinbefore described with reference to the accompanying drawing.

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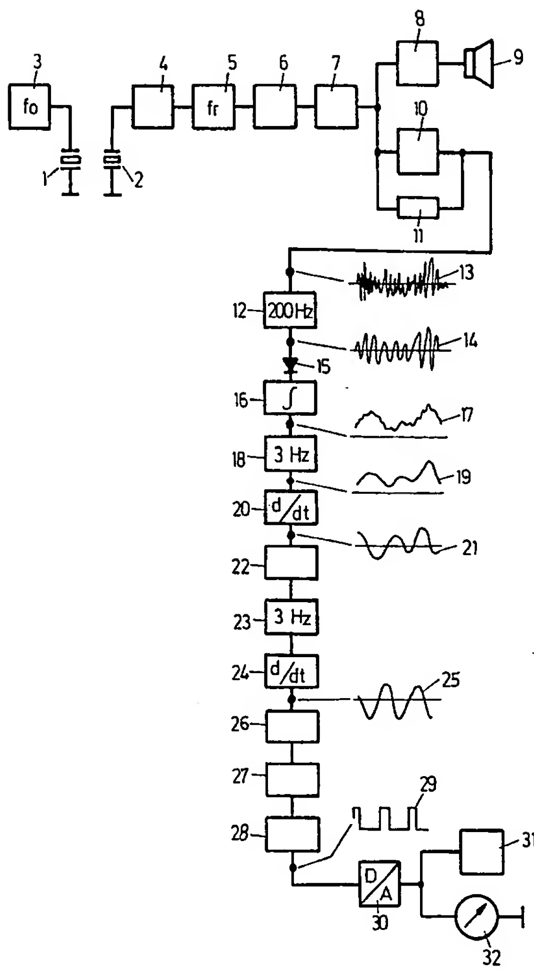
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